EPCOS

PTC Thermistors

General technical information

Date: November 2009

1 Introduction

PTC thermistors are ceramic components whose electrical resistance rapidly increases when a certain temperature is exceeded. This feature makes them ideal for use in countless applications of modern electrical and electronic engineering, for example as resettable fuses against current overload or as shortcircuit protection in motors. PTC thermistors are used in electronic lamp ballasts and switch-mode power supplies for delayed switching, and to degauss shadow masks in picture tubes. You find special motor starter PTC thermistors in the compressors of refrigerators for instance. Thermal protection of motors and transformers is another example of the versatility of PTC thermistors. The applications extend to measurement and control engineering, to entertainment, household and automotive electronics, plus data systems and telecommunications of course. PTC thermistors are also suitable as self-regulating heating elements, in auxiliary heating, nozzle heating and carburetor preheating in automobiles, as well as in many domestic appliances such as door locks for washing machines, or glue guns and hair curlers.

The different models of PTC thermistors from EPCOS are equally diverse, offering the matching solution for virtually every application. If you are unable to find the right PTC in this data book, contact one of our sales offices. They will help you, together with the EPCOS development department for PTCs, to find the right solution for your application.

2 Definition

A PTC thermistor is a thermally sensitive semiconductor resistor. Its resistance value rises sharply with increasing temperature after a defined temperature (reference temperature) has been exceeded.

The very high positive temperature coefficient (PTC) of the resistance above the reference temperature has given the PTC thermistor its name.

Applicable standards are EN 60738-1, IEC 60738-1, DIN 44081 and DIN 44082.

3 Structure and function

PTC thermistors are made of doped polycrystalline ceramic on the basis of barium titanate. Generally, ceramic is known as a good insulating material with a high resistance. Semiconduction and thus a low resistance are achieved by doping the ceramic with materials of a higher valency than that of the crystal lattice. Part of the barium and titanate ions in the crystal lattice is replaced with ions of higher valencies to obtain a specified number of free electrons which make the ceramic conductive.

The material structure is composed of many individual crystallites (figure 1). At the edge of these monocrystallites, the socalled grain boundaries, potential barriers are formed. They prevent free electrons from diffusing into adjacent areas. The result is high resistance of the grain boundaries. However, this effect is neutralized at low temperatures. High dielectric constants and sudden polarization at the grain boundaries prevent the formation of potential barriers at low temperatures enabling a smooth flow of free electrons.

Above the ferroelectric Curie temperature, dielectric constant and polarization decline so far that there is strong growth of the potential barriers and thus of resistance. In a certain range of temperature above the Curie temperature T_C, the resistance of the PTC thermistor rises exponentially. Beyond the range of the positive temperature coefficient α the number of free charge carriers is increased by thermal activation. The resistance then decreases and exhibits a negative temperature characteristic (NTC) typical of semiconductors (see figure 2).

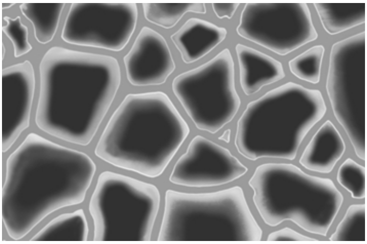

Figure 1

Schematic representation of the polycrystalline structure of a PTC thermistor.

The PTC resistance R_{PTC} is composed of individual crystal and grain boundary resistances. The grain boundary resistance is strongly temperature dependent.

$R_{PTC} = R_{grain} + R_{boundary}$

$R_{grain\ boundary} = f\ (T)$

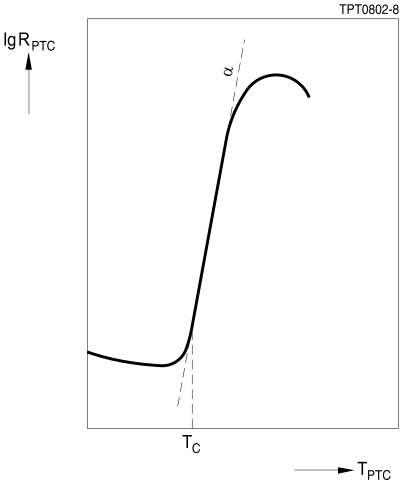

Figure 2

T_C = ferroelectric Curie temperature

α = temperature coefficient

With rising temperature, the resistance of the PTC thermistor initially decreases and rises then steeply. Beyond the range of the positive temperature coefficient α the resistance again decreases.

4 Manufacturing

Mixtures of barium carbonate, titanium oxide and other materials whose composition produces the desired electrical and thermal characteristics are ground, mixed and compressed into disks, washers, rods, slabs or tubular shapes depending on the application.

These blank parts are then sintered, preferably at temperatures below 1400 °C. Afterwards, they are carefully contacted, provided with connection elements depending on the version and finally coated or encased.

A flow chart in the quality section of this book (see page) shows the individual processing steps in detail. The chart also illustrates the extensive quality assurance measures taken during manufacture to guarantee the constantly high quality level of our thermistors.

5 Characteristics

A current flowing through a thermistor may cause sufficient heating to raise the thermistor's temperature above the ambient. As the effects of self-heating are not always negligible, a distinction has to be made between the characteristics of an electrically loaded thermistor and those of an unloaded thermistor. The properties of an unloaded thermistor are also termed "zero-power characteristics".

5.1 Unloaded PTC thermistors

5.1.1 Temperature dependence of resistance

The zero-power resistance value R (T) is the resistance value measured at a given temperature T with the electrical load kept so small that there is no noticeable change in the resistance value if the load is further reduced.

For test voltages, please refer to the individual types (mostly ≤ 1.5 V).

Figure 3 shows the typical dependence of the zero-power resistance on temperature. Because of the abrupt rise in resistance (the resistance value increases by several powers of ten), the resistance value is plotted on a logarithmic scale (ordinate) against a linear temperature scale (abscissa).

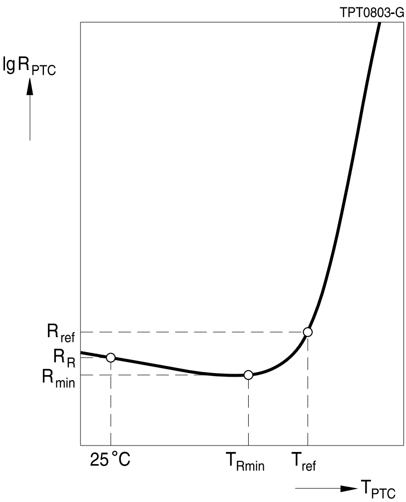

Figure 3

Typical resistance/temperature characteristic

$R_{PTC} = f\ (T_{PTC})$

R_R Rated PTC resistance (resistance value at 25 °C)

R_{min} Minimum resistance

T_{Rmin} Temperature at R_{min}

R_{ref} Reference resistance $R_{ref} = 2 \cdot R_{min}$

T_{ref} Reference temperature (resistance value reaches $R_{ref} = 2 \cdot R_{min}$)

5.1.2 Rated resistance R_R

The rated resistance R_R is the resistance value at temperature T_R. PTC thermistors are classified according to this resistance value. The temperature T_R is 25 °C, unless otherwise specified.

5.1.3 Minimum resistance R_{min}

The beginning of the temperature range with a positive temperature coefficient is specified by the temperature T_{Rmin}. The value of the PTC resistance at this temperature is designated as R_{min} . This is the lowest zero-power resistance value which the PTC thermistor is able to assume. R_{min} is often given as a calculable magnitude without stating the corresponding temperature. The R_{min} values specified in this data book allow for the R tolerance range of the individual types and represent the lower limit.
For PTC heaters the R_{min} values given in the data sheet section are measured at the rated voltage.

5.1.4 Reference resistance R_{ref} at reference temperature T_{ref}

The start of the steep rise in resistance, marked by the reference temperature T_{ref}, which corresponds approximately to the ferroelectric Curie point, is significant for the application. For the individual types of PTC thermistors it is defined as the temperature at which the zero-power resistance is equal to the value $R_{ref} = 2 \cdot R_{min}$. In the data sheet section we specify typical values of T_{ref}.

5.1.5 Temperature coefficient α

The temperature coefficient of resistance α is defined as the relative change in resistance referred to the change in temperature and can be calculated for each point on the R/T curve by:

$$\alpha = \frac{1}{R} \cdot \frac{dR}{dT} = \frac{d\ln R}{dT} = \ln 10 \cdot \frac{d\lg R}{dT}$$

In the range of the steep rise in resistance above R_{ref}, α may be regarded as being approximately constant. The following relation then applies:

$$R_{PTC} \leq R_1,\ R_2 \leq R_{PTC} \rightarrow \alpha = \frac{\ln\left(\frac{R_2}{R_1}\right)}{T_2 - T_1}$$

Within this temperature range, the reverse relation can be equally applied:

$$R_2 = R_1 \cdot e^{\alpha \cdot (T_2 - T_1)}$$

The values of α for the individual types relate only to the temperature range in the steep region of the resistance curve, which is of primary interest for many applications.

5.1.6 Sensing temperature T_{sense}

For PTC temperature sensors the pair of values T_{sense}, R_{sense} is specified instead of T_{ref}, R_{ref}. The temperature relating to a defined resistance value in the steep region of the curve R_{sense} is given as the **sensing temperature** T_{sense} .

5.1.7 Resistance matching $R_{25,match}$

The resistance matching $R_{25,match}$ specifies the resistance tolerance at 25 °C per packing unit. For example, if $R_{25,match}$ is specified as ±0.5 Ω, all parts within one packing unit will not differ by more than 1 Ω.

5.2 Electrically loaded PTC thermistors

When a current flows through the thermistor, the device will heat up more or less by power dissipation. This self-heating effect depends not only on the load applied, but also on the thermal dissipation factor G_{th} of the thermistor itself.
Self-heating of a PTC thermistor resulting from an electrical load can be calculated as follows:

$$P = V \cdot I = \frac{dH}{dt} = G_{th} \cdot \left(T - T_A\right) + C_{th} \cdot \frac{dT}{dt}$$

P	Power applied to PTC	T	Instantaneous temperature of PTC
V	Instantaneous value of PTC voltage	T_A	Ambient temperature
I	Instantaneous value of PTC current	C_{th}	Heat capacity of PTC
dH/dt	Change of stored heating energy over time	dT/dt	Change of temperature over time
G_{th}	Thermal dissipation factor of PTC		

5.2.1 Surface temperature T_{surf}

T_{surf} is the temperature reached on the thermistor's surface when it has been operated at specified rated voltage and in a state of thermal equilibrium with the ambient for a prolonged period of time. The specifications in the data sheet section refer to an ambient temperature of 25 °C and are typical values.

5.2.2 Current/voltage characteristic

The properties of electrically loaded PTC thermistors (in self-heated mode) are better described by the I/V characteristic than by the R/T curve (see figure 4). It illustrates the relationship between voltage and current in a thermally steady state in still air at 25 °C, unless another temperature is specified.

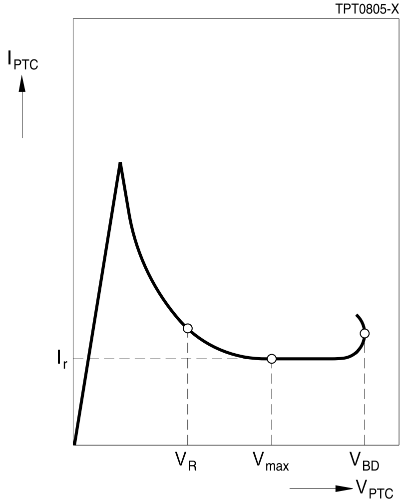

Figure 4
I/V characteristic of a PTC thermistor

- I_r Residual current at applied voltage V_{max} (current is balanced)
- V_{max} Maximum operating voltage
- V_R Rated voltage ($V_R < V_{max}$)
- V_{BD} Breakdown voltage ($V_{BD} > V_{max}$)

5.2.3 Rated current I_R and switching current I_S

It is important to know at which current the PTC thermistor will not trip and at which currents the thermistor will reliably go into high-resistance mode. For this reason we specifiy the rated current I_R and the switching current I_S.

Rated current I_R: At currents $\leq I_R$ the PTC thermistor reliably remains in low-resistance mode.

Switching current I_S: At currents $\geq I_S$ the PTC thermistor reliably goes into high-resistance mode.

The currents specified in the data sheets refer to T_A = 25 °C, unless otherwise stated.

5.2.4 Residual current I_r

The **residual current** I_r is the current developed at applied maximum operating voltage V_{max} and at thermal equilibrium (steady-state operation). The currents specified in the data sheets refer to T_A = 25 °C.

5.2.5 Maximum rated current I_{max} and maximum switching current I_{Smax}, permissible number of switching cycles N

In electrically loaded PTC thermistors electrical power is converted into heat. The high loads generated for a short period of time during the heating phase (the PTC thermistor is in low-resistance mode when the operating voltage is applied) are limited by the specification of maximum permissible currents I_{max}, I_{Smax} and voltages V_{max} in the data sheet section.

The number of heating processes is also an important criterion. The permissible number of switching cycles not affecting function or service life N is given in the data sheets and applies to operation at specified maximum loads.

5.2.6 Maximum operating voltage V_{max}, rated voltage V_R, maximum measuring voltage $V_{meas,max}$, breakdown voltage V_{BD} and maximum link voltage $V_{link,max}$

The maximum operating voltage V_{max} is the highest voltage which may be continuously applied to the thermistor at the ambient temperatures specified in the data sheets (still air, steady-state, high-resistance mode).

The **rated voltage V_R** is the supply voltage lying below V_{max}.

The **maximum measuring voltage $V_{meas,max}$** is the highest voltage that may be applied to the thermistor for measuring purposes (only applies to sensors).

The **breakdown voltage V_{BD}** is the measure of a thermistor's maximum voltage handling capability. Beyond V_{BD} the PTC thermistor no longer exhibits its characteristic properties.

The **maximum link voltage $V_{link,max}$** is the maximum DC voltage which can occur across the DC link or filter capacitor.

5.2.7 Switching time t_S

If V_{max} and I_{max} are known, it is possible to describe the PTC thermistor's switch-off behavior in terms of **switching time t_S.** This is the time it takes at applied voltage for the current passing through the PTC to be reduced to half of its initial value. The t_S values apply to T_A = 25 °C.

5.2.8 Insulation test voltage V_{ins}

The insulation test voltage V_{ins} is applied between the body of the thermistor and its encapsulation for a test period of 5 s.

5.3 Thermal characteristics

5.3.1 Thermal cooling time constant τ_{th}

The thermal cooling time constant refers to the time necessary for an unloaded thermistor to vary its temperature by 63.2% of the difference between its mean temperature and the ambient temperature.

Equation for temperature change: $T(t_2) = T(t_1) \pm 0.632\ (T(t_1) - T_A)$ with $t_2 - t_1 = \tau_{th}$

5.3.2 Thermal threshold time t_a

The thermal threshold time t_a is the time an unloaded PTC thermistor needs to increase its temperature from starting temperature (25 °C) to reference temperature T_{ref} or sensing temperature T_{sense} by external heating.

5.3.3 Response time t_R for level sensors

The response time t_R is the time a PTC thermistor requires to recognize the change of power dissipation resulting from a change of the surrounding medium at applied voltage. After this period of time the residual currents assigned to the individual media become effective in the device.

5.3.4 Settling time t_E for level sensors

The settling time t_E refers to the time the PTC thermistor needs to reach operating condition after the operating voltage has been applied.

6 Notes on operating mode

6.1 Voltage dependence of resistance

The R/T characteristic shows the relationship between resistance and temperature at zero power, i.e. when self-heating of the PTC thermistor is negligible.

The resistance of the PTC thermistor is composed of the grain resistance and the grain boundary transition resistance. Particularly in the hot state, the strong potential barriers are determining resistance. Higher voltages applied to the PTC thermistor therefore drop primarily at the grain boundaries with the result that the high field strengths dominating here produce a break-up of the potential barriers and thus a lower resistance. The stronger the potential barriers are, the greater is the influence of this "varistor effect" on resistance. Below the reference temperature, where the junctions are not so marked, most of the applied voltage is absorbed by the grain resistance. Thus the field strength at the grain boundaries decreases and the varistor effect is quite weak.

Figure 5 shows the typical dependence of resistance on field strength. It can be seen that the difference in resistance is largest between $R(E_1)$, $R(E_2)$ and $R(E_3)$ at temperature T_{max} and thus in the region of maximum resistance.

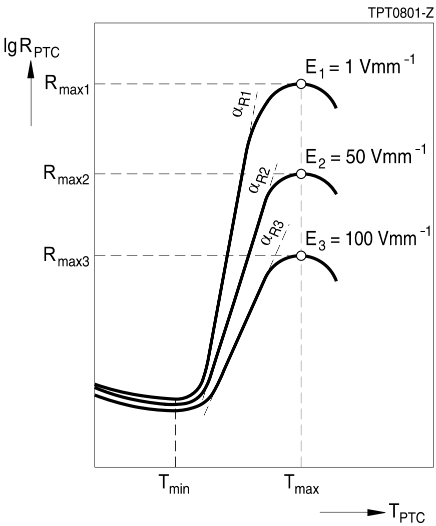

Figure 5
Influence of field strength E on the R/T characteristic (varistor effect)
$\alpha_{R1} > \alpha_{R2} > \alpha_{R3}$

Due to this dependence on the positive temperature coefficient of the field strength, operation on high supply voltages is only possible with PTC thermistors that have been designed for this purpose by means of appropriate technological (grain size) and constructional (device thickness) measures.

The R/T curves in the data sheet section are zero-power characteristics.

6.2 Frequency dependence of resistance

Due to the structure of the PTC thermistor material, the PTC thermistor on AC voltage is not a purely ohmic resistor. It acts as a capacitive resistor because of the grain boundary junctions (see equivalent circuit diagram, figure 6).

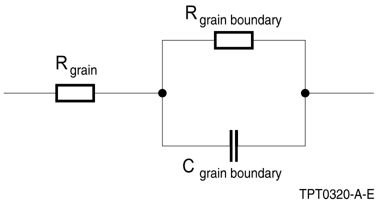

Figure 6
Equivalent circuit diagram of PTC thermistor on AC voltage

The impedance measured at AC voltage decreases with increasing frequency. The dependence of the PTC resistance on temperature at different frequencies is shown in figure 7. So use of the PTC thermistor in the AF and RF ranges is not possible, meaning that applications are restricted to DC and line frequency operation.

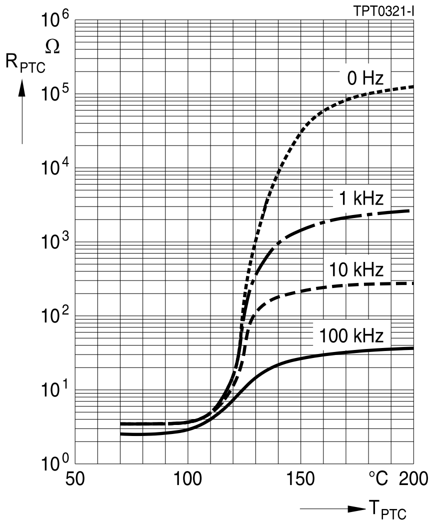

Figure 7
Influence of frequency on R/T characteristic

6.3 Influence of heat dissipation on PTC temperature

Figure 8 shows the electrical power P_{el} converted in a PTC thermistor as a function of its temperature. At a given operating voltage an operating point is established in the PTC depending on the ambient temperature and thermal conduction from the thermistor to the environment.

The PTC thermistor heats up to an operating temperature above the reference temperature, for example (operating point A_1 in figure 8). If the ambient temperature rises or the heat transfer to the environment decreases, the heat generated in the PTC thermistor can no longer be dissipated so the PTC will increase its temperature. Its operating point moves down the curve, e. g. to A_2, causing a considerable reduction in current.

This limiting effect is maintained as long as T_{max} is not exceeded. An increase in temperature beyond T_{max} would lead to the destruction of the PTC thermistor at a given operating voltage.

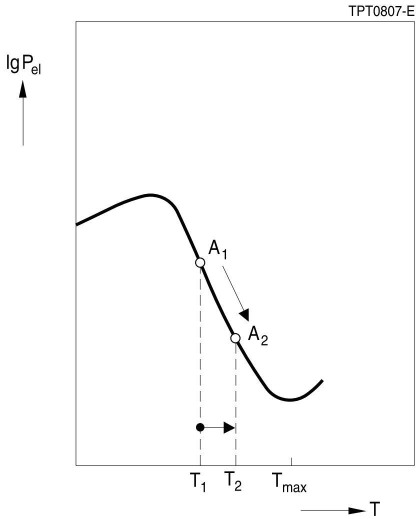

Figure 8
Electrical power P_{el} in a PTC thermistor versus PTC temperature

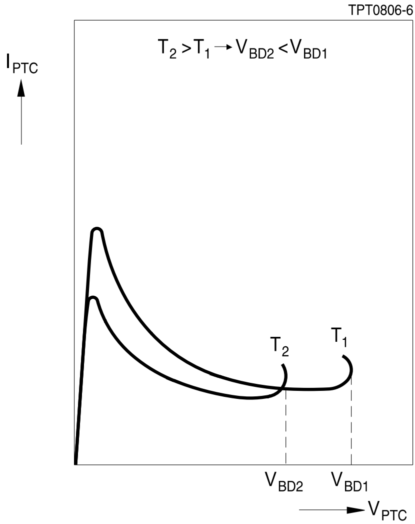

Figure 9
Influence of the ambient temperature on the I/V characteristic

6.4 Influence of ambient temperature on the I/V characteristic

Figure 9 shows two I/V characteristics of one and the same PTC thermistor for two different ambient temperatures T_1 and T_2, with $T_1 < T_2$. At the higher temperature the PTC thermistor has a higher resistance value although the conditions are otherwise the same. Therefore, it carries less current. The curve for T_2 is thus below that for T_1. The breakdown voltage, too, depends on the ambient temperature. If the latter is higher, the PTC thermistor reaches the critical temperature where breakdown occurs on lower power or operating voltage. V_{BD2} is therefore lower than V_{BD1}.